LOAD DEPENDENCE OF HARDNESS AND FRACTURE TOUGHNESS VALUES ON HARDMETALS

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Abstract

Fracture toughness is one of the most important parametars for tool aplications and preformance assesment of WC-Co hardmetals. In this paper the effect of applied load on the hardness and fracture toughness of hardmetal is investigated. The tested sample contained 9 wt. % of Co and was manufactured by sinter-HIP process. Hardness measurements were carried out by Vickers method with four different loads: 29,42 N (HV3) 49,03 N (HV5) 196,13 N (HV20) and 294,20 N (HV30). Thirty measurements were conducted with each value of the applied load. At all measurements the sample surface showed cracks that spread from the vertices of the indentation. Dimensional characteristics of generated indentation and the resulting length of the cracks were measured by using an optical microscope, immediately after unloading. Fracture toughness was determined by Palmqvist method according to ISO 28079: 2009.

Keywords*: Hardmetal, Fracture toughness, Hardness, Indentation load*

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1. INTRODUCTION

Hardmetals (WC-Co system), known by its commercial name Widia, are the most successful representatives of sintered materials produced by powder metallurgy. The area of application for hardmetals is expanding on a daily basis because of their superior mechanical and tribological properties. With the use of nano-sized powders for sintering, hardmetals show high hardness levels and at the same time good fracture toughness values [1]. That is the reason why they are used in metal cutting processes and machining of stone, ceramics and other hard materials [2]. Designing tools with advanced properties, achieving satisfactory fracture toughness at high hardness values is nowadays one of the main directions in development of hardmetals. With the introduction of fracture mechanics in assessment of tool life, great emphasis is placed on fracture toughness of materials. Unlike determininig hardness values, the fracture toughness determinaton is highly complex, particularly in brittle materials [3]. Today, a great number of different test methods for the evaluation of fracture toughness are being developed, but most of them have theoretically disputed setup of experiments. Especially in the case of indentation techniques that require expensive and sophisticated equipment for precise experimental measurement of crack propagation [4, 5]. However Palmqvist indentation method (ISO 28079: 2009) has so far proven to be very successful, but there are no adequate informations about the influence of indentation load on the fracture toughness values for hardmetal products [6, 7].

2. MATERIALS AND METHODS

All tests were carried out on the sample of hardmetal consolidated by sinter-HIP technology. The sinter-HIP process was preceded by mixing of tungsten carbide (WC) and cobalt (Co) powders, milling, drying, granulating and compacting of the obtained mixture. The compacted sample was then sintered in the vacuum furnace and subsequently hot isostatic pressesed (HIP) in one cycle at high pressures and temperatures, Figure 1.

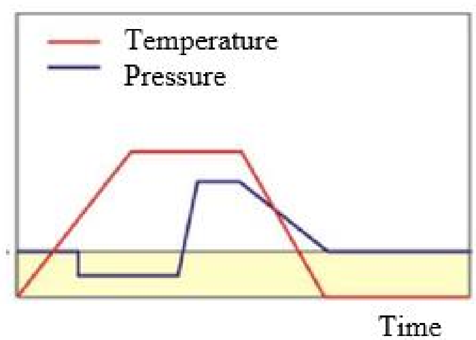

Figure 1: Sinter-HIP process [1]

The mentioned process represents the very top in powder metallurgy consolidation, which gives a theoretical density product without pores. That kind of process ensures the mentioned superior mechanical properties. The sample contained 9 wt. % Co and was compacted at a pressure of 300 MPa. Sintering was performed at a temperature of 1350 °C with the subsequent introduction of argon gas with 80 bars of pressure [1]. Surface preparation (grinding and polishing) prior to hardness measurements affects the hardness and fracture toughness values. Therefore, it is important to adequately prepare a sample surface. Prior to examination, the sample was polished with a series of diamond pastes up to 1 μm finish. The polished specimen surface is then penetrated by a Vickers pyramidal indenter to create a deformed region beneath and in the vicinity of the indentation which generate the cracks emanating from the vertices of the square Vickers indentation. The length of cracks is inversely proportional to the values of fracture toughness. Fracture toughness determination and hardness measurement were performed under following loads: 29,42 N (HV3), 49,03 N (HV5), 196,13 N (HV20), 294,20 N (HV30). Thirty indentations were made under ambient laboratory conditions on the reference hardness tester Indentec, UK; type: 5030 TKV while the diagonal and crack were measured on the optical microscope, immediately after unloading. Vickers indentation with characteristic values measured after removal of the load is presented in Fig. 2.

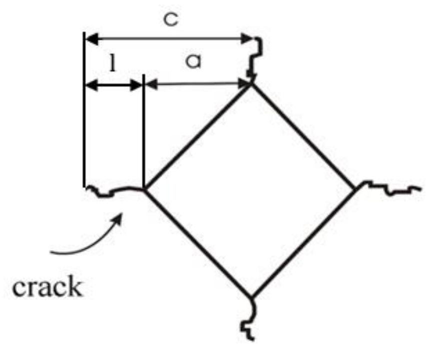

Figure 2: Vickers indentation with characteristic values

The length of cracks, the indentation load, the diagonal of indentation, the hardness and an empirical calibration constant are used to calculate fracture toughness according to Palmqvist. The model is presented with equation [8]:

$$W_K = A\sqrt{HV} \cdot \sqrt{W_G} \quad (1)$$

where is:

W_K – fracture toughness (MPa·√m),

A – empirical constant with a value 0,0028,

W_G– ratio of indent load to crack length obtained by equation[8]:

$$W_G = \frac{F}{T} \text{ (N/mm)}, \quad (2)$$

T – total crack length ($T=l_1+l_2+l_3+l_4$)

HV – Vickers hardness defined by formula[8]:

$$HV = \frac{1{,}8544 \cdot F}{d^2} \quad (3)$$

where is:

F –applied load (N),

d – mean value of the indentation diagonals (mm).

3. RESULTS AND DISCUSSION

Statistical analysis results of Vickers hardness (HV) obtained from thirty measurements, including the minimum, the maximum, the arithmetic average value and its standard deviation are summarized in Table 1.

Table 1: Statistical analysis of the hardness values

Hardness	Average	Standard deviation	Minimum	Maximum
***HV*3**	**1973,8**	**63,6**	**1886,8**	**2061,3**
***HV*5**	**1933,1**	**27,5**	**1873,4**	**1984,7**
***HV*20**	**1864,9**	**24,6**	**1817,5**	**1919,5**
***HV*30**	**1841,5**	**30,8**	**1786,8**	**1910,3**

Vickers indentations made by various indentation loads are presented in Fig. 3.

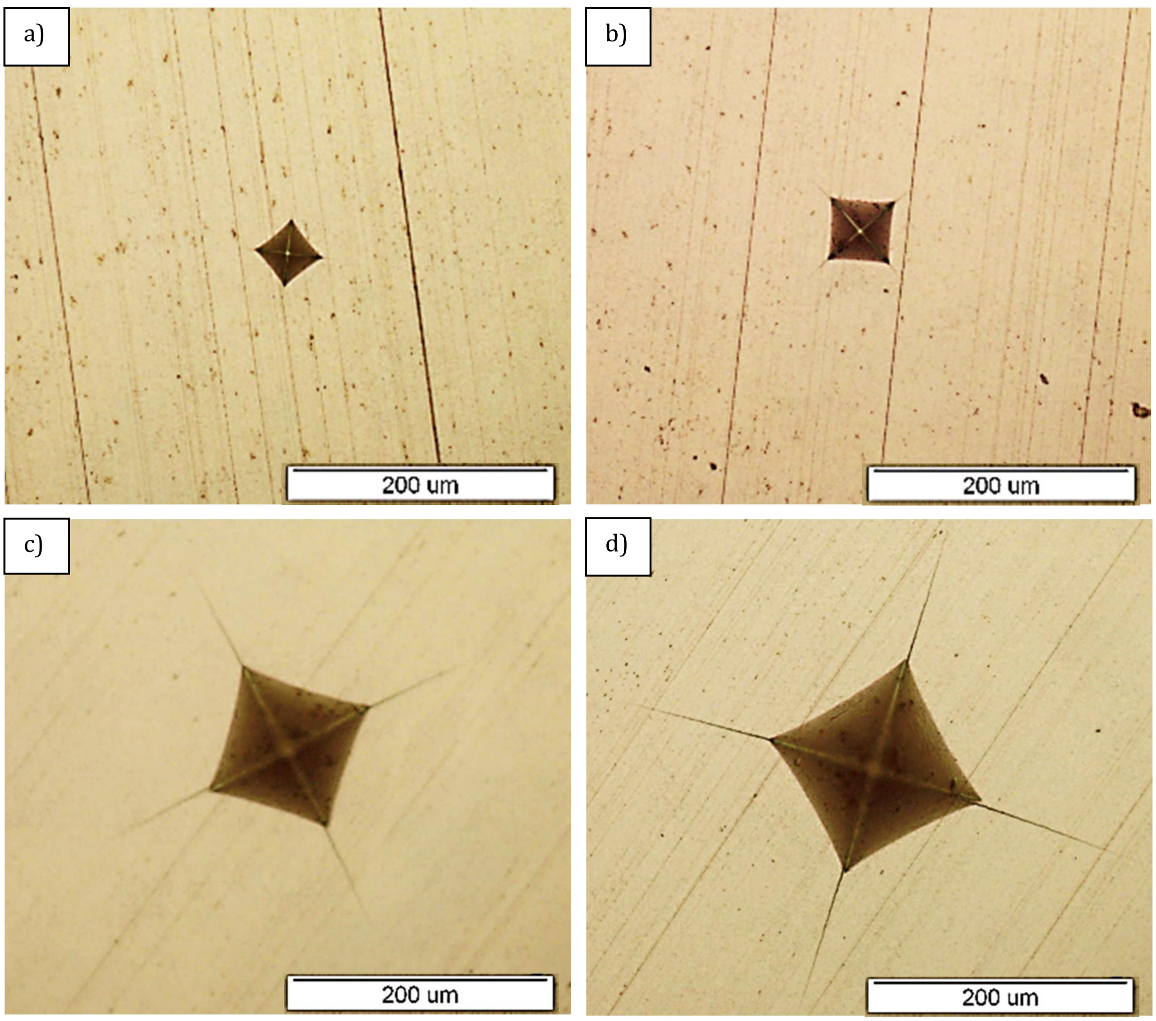

Figure 3: Optical micrographs of Vickers indentations and cracks by different indentation load (a) 29,42 N, (b) 49,03 N, (c) 196,13 N, (d) 294,20 N

At all indentation loads is created a deformed region beneath and in the vicinity of the indentation, which leads to the generation of four cracks emanating from the vertices of the square indentation. As can be seen from the figure 3 the crack length could be easily measured.

Figure 4 shows the dependence of hardness and applied indentation load.

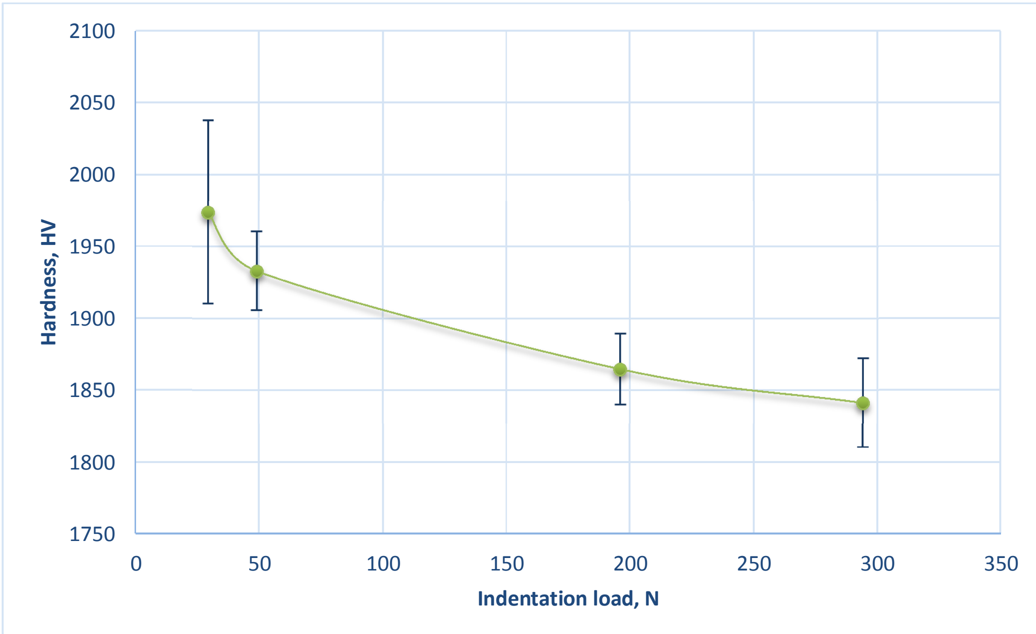

Figure 4: Dependence of hardness values on indentation load

The cracks that originated from the vertices of the Vickers indentation were used to compute the fracture toughness (K_{Ic}) according to Palmqvist [9]. The results are summarized in Table 2.

Table 2: Statistical analysis of fracture toughness values

Load 1. N	Average 2. MPa·m$^{1/2}$	Standard deviation MPa·m$^{1/2}$	Minimum 3. MPa·m$^{1/2}$	Maximum 4. MPa·m$^{1/2}$
29,42	10,94	0,53	9,80	12,34
49,03	10,20	0,50	9,57	11,42
196,13	9,62	0,27	9,12	10,19
294,20	9,76	0,37	9,43	11,38

The results indicate that the change of the indentation load, also varies the amount of calculated fracture toughness, as shown in Fig. 5.

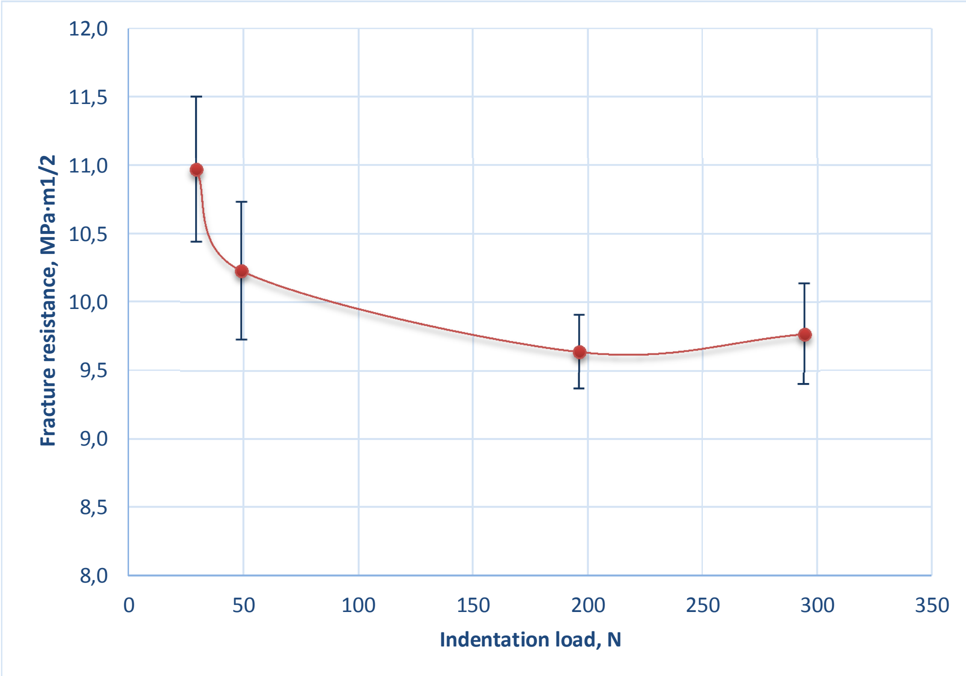

Figure 5: Dependence of fracture toughness values on the indentation load

4. CONCLUSION

The results presented in this paper can be summarized as follows:

- Hardness values of the investigated hardmetal depend on the applied indentation load. The investigated material shows a normal indentation size effect because the hardness values reduce with increasing of test force. The hardness value at minimum load of 29,42 N (HV3) was 1973,8 HV. The hardness value at maximum load of 294,20N (HV30) was 1841,5 HV.
- The cracks occur from the vertices of indentation for all applied loads.
- The fracture toughness values of the investigated hardmetal depend on the applied indentation load and the resulting crack length. When different loads are applied to calculate fracture toughness which depends on the crack length, then different fracture toughness values are obtained for the same material. For applied model differences in the calculated fracture toughness values can be up to ≈12 %. Therefore, it is important to choose an appropriate indentation load which will result reliable fracture toughness value. The Palmqvist crack model is very suitable for the analysis of the fracture resistance of the investigated hardmetal, but only when high indentation loads are applied.

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